TITLE
HIGH TEMPERATURE SUPERCONDUCTOR MINI-FILTERS AND MINI-MULTIPLEXERS WITH SELF-RESONANT SPIRAL RESONATORS

CROSS-REFERENCE TO RELATED APPLICATION

5   This application is a continuation of application Serial No. 09/592,466, filed 9 June 2000 (which is incorporated as a part hereof as fully as if set forth at length herein), which is a continuation of application Serial No. 09/079,467, filed 15 May 1998,

10   now US 6,108,569.

BACKGROUND OF THE INVENTION

      This invention relates to high temperature superconductor (HTS) mini-filters and mini-multiplexers

15   with self-resonant spiral resonators as the building blocks, which have the advantages of very small size and very low cross-talk between adjacent filters.

      HTS filters have the advantages of extremely low in-band insertion loss, high off-band rejection, steep

20   skirts, due to extremely low loss in the HTS materials. The HTS filters have many applications in telecommunication, instrumentation and military equipment. However, for the regular design of a HTS filter, the resonators as its building blocks are large

25   in size. In fact, at least one dimension of the resonator is equal to approximately a half wavelength. For low frequency HTS filters with many poles, the regular design requires a very large substrate area. The substrates of thin film HTS circuits are special

30   single crystal dielectric materials with high cost. Moreover, the HTS thin film coated substrates are even more costly. Therefore, for saving material cost, it is desirable to reduce the HTS filter size without sacrificing its performance. Furthermore, for the HTS

35   filter circuits, the cooling power, the cooling time, and the cost to cool it down to operating cryogenic temperature increases with increasing circuits' size.

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These are the reasons to reduce the HTS filter size without sacrificing its performance.

There is a prior art design to reduce the HTS filters size, i. e. by using lumped circuit" elements such as capacitors and inductors to build the resonator used as the building blocks of HTS filters. This approach does reduce the size of HTS filters. However, it also has problems. First, the regular element inductors such as the spiral inductors shown in Figures 1a and 1b have wide spread magnetic fields, which reach the region far beyond the inductor and undesirable cross-talk between adjacent circuits. Second, in the lumped circuit filter design, the two ends of the spiral inductor must be connected to other circuit components such as capacitors etc. But one of the inductor's two ends is located at the center of the spiral, which cannot be directly connected to other components. In order to make the connection from the center end of the spiral inductor to another component, an air-bridge or multi-layer over-pass must be fabricated on top of the HTS spiral inductor. They not only degrade the performance of the filter, but also are difficult to fabricate. Third, there are two ways to introduce lumped capacitors: One is using a "drop-in" capacitor, which usually has unacceptable very large tolerance. The other is using a planar interdigital capacitor, which requires a very narrow gap between two electrodes with high rf voltage across them, which may cause arcing.

The purpose of this invention is to use self-resonant spiral resonators to reduce the size of HTS filters and at the same time to solve the cross-talk and connection problems.

SUMMARY OF THE INVENTION

One embodiment of the invention is a self-resonating spiral resonator including a high temperature superconductor line oriented in a spiral fashion such that adjacent lines are spaced from each

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other by a gap distance which is less than the line width; and wherein a central opening in the resonator has a dimension approximately equal to that of the gap distance in each dimension.

5   Another embodiment of the invention is a high temperature superconductor mini-filter including

a) a substrate having a front side and a back side;

b) at least two self-resonant spiral
10   resonators in intimate contact with the front side of the substrate;

c) at least one inter-resonator coupling mechanism;

d) an input coupling circuit comprising a
15   transmission line with a first end connected to an input connector of the filter and a second end coupled to a first one of the at least two self-resonant spiral resonators;

20   e) an output coupling circuit comprising a transmission line with a first end connected to an output connector of the filter and a second end coupled to a last one of the at least two self-resonant
25   spiral resonators;

f) a blank high temperature superconductor film disposed on the back side of the substrate as a ground plane; and

g) a blank gold film disposed on the blank
30   high temperature superconductor film.

In another embodiment of the invention, the mini-filters have a strip line form and further include:

a) a superstrate having a front side and a back side, wherein the front side of the
35   superstrate is positioned in intimate contact with the at least two resonators disposed on the front side of the substrate;

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b) a second blank high temperature superconductor film disposed at the back side of the superstrate as a ground plane; and

5 c) a second blank gold film disposed on the surface of said second high temperature superconductor film.

A further embodiment of the invention is a mini-multiplexer including at least two of the mini-filters

10 with different and non-overlapping frequency bands; a distribution network with one common port as an input for the mini-multiplexer and multiple distributing ports, wherein one distributing port is connected to a corresponding input of one mini-filter; and a multiple

15 of output lines, wherein each output line is connected to a corresponding output of one mini-filter.

A further embodiment of the invention is a high temperature superconductor mini-filter including:

(a) a substrate having a front side and a back

20 side;

(b) at least two self-resonant spiral resonators in intimate contact with the front side of the substrate, each of said resonators independently comprising a high temperature

25 superconductor line oriented in a spiral fashion (i) such that adjacent lines are spaced from each other by a gap distance which is less than the line width; and (ii) so as to form a central opening within the

30 spiral, the dimensions of which are approximately equal to the gap distance;

(c) at least one inter-resonator coupling;

(d) an input coupling circuit comprising a transmission line with a first end connected

35 to an input connector of the filter and a second end coupled to a first one of the at least two self-resonant spiral resonators;

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(e) an output coupling circuit comprising a transmission line with a first end connected to an output connector of the filter and a second end coupled to a last one of the at least two self-resonant spiral resonators;

(f) a blank high temperature superconductor film disposed on the back side of the substrate as a ground plane;

(g) a film disposed on the blank high temperature superconductor film as the contact to a case for said mini-filter;

(h) a superstrate having a front side and a back side, wherein the front side of the superstrate is positioned in intimate contact with the at least two resonators disposed on the front side of the substrate;

(i) a second blank high temperature superconductor film disposed at the back side of the superstrate as a ground plane; and

(j) a second film disposed on the surface of said second high temperature superconductor film as a contact to a case for said mini-filter.

A further embodiment of the invention is a high temperature superconductor mini-multiplexer including:

(a) at least two mini-filters, each mini-filter having a frequency band which is different from and does not overlap with the frequency bands of each other mini-filter;

(b) a distribution network with one common port as an input for the mini-multiplexer and multiple distributing ports, wherein one distributing port is connected to a corresponding input of one mini-filter; and

(c) a multiple of output lines, wherein one output line is connected to a corresponding output of one mini-filter;

wherein each of said at least two mini-filters comprises:

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(d) a substrate having a front side and a back side;

(e) at least two self-resonant spiral resonators in intimate contact with the front side of the substrate, each of said resonators independently comprising a high temperature superconductor line oriented in a spiral fashion (i) such that adjacent lines are spaced from each other by a gap distance which is less than the line width; and (ii) so as to form a central opening within the spiral, the dimensions of which are approximately equal to the gap distance;

(f) at least one inter-resonator coupling;

(g) an input coupling circuit comprising a transmission line with a first end connected to an input connector of the filter and a second end coupled to a first one of the at least two self-resonant spiral resonators;

(h) an output coupling circuit comprising a transmission line with a first end connected to an output connector of the filter and a second end coupled to a last one of the at least two self-resonant spiral resonators;

(i) a blank high temperature superconductor film disposed on the back side of the substrate as a ground plane; and

(j) a film disposed on the blank high temperature superconductor film as the contact to a case for said mini-filter.

These and other aspects of the invention and the preferred embodiments will become apparent on a further reading of the specification and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows the prior art conventional spiral inductors, in which Figure 1a shows a square spiral inductor and Figure 1b shows a circular spiral inductor.

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Figure 2 shows the present self-resonant spiral resonators in different forms. Figure 2a shows a self-resonant spiral resonator in the rectangular form. Figure 2b shows a self-resonant spiral resonator in the rectangular form with rounded corners. Figure 2c shows a self-resonant spiral resonator in the octagon form. Figure 2d shows a self-resonant spiral resonator in the circular form.

Figure 3 shows a first embodiment of the present invention of a microstrip line 4-pole HTS mini-filter with self-resonant rectangular spiral resonators with rounded corners, center tuning pads, and parallel lines input/output coupling circuits. Fig. 3a shows the front view thereof, and Fig. 3b shows the cross section view thereof.

Figure 4 shows a second embodiment of the present invention of a microstrip line 4-pole HTS mini-filter with self-resonant rectangular spiral resonators, transverse offset inter-resonator coupling adjustment, and inserted line input and output coupling circuits. Fig. 4a shows the front view thereof, and Fig. 4b shows the cross section view thereof.

Figure 5 shows a third embodiment of the present invention of a microstrip line 4-pole HTS mini-filter with self-resonant octagon spiral resonators, transverse offset inter-resonator coupling adjustment, and inserted line coupling input and output circuits. Fig. 5a shows the front view thereof, and Fig. 5b shows the cross section view thereof.

Figure 6 shows a fourth embodiment of the present invention of a microstrip line 4-pole HTS mini-filter with self-resonant circular spiral resonators, circular center tuning pads, and parallel lines input/output coupling circuits. Fig. 6a shows the front view thereof, and Fig. 6b shows the cross section view thereof.

Figure 7 shows a fifth embodiment of the present invention of a microstrip line 5-pole HTS mini-filter

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with four self-resonant rectangular spiral resonators,
one symmetrical double spiral resonator, and inserted
line input and output coupling circuits. Fig. 7a shows
the front view thereof, and Fig. 7b shows the cross

5   section view thereof.

Figure 8 shows a first embodiment of the present
invention of a microstrip line mini-multiplexer with
two channels. Each channel comprises an 8-pole HTS
mini-filter with self-resonant rectangular spiral

10   resonators, and parallel lines input/output coupling
circuits. The input circuit of the multiplexer is in
the binary splitter form. Fig. 8a shows the front view
thereof, and Fig. 8b shows the cross section view
thereof.

15   Figure 9 shows a second embodiment of the present
invention of a microstrip line mini-multiplexer with
four channels. Each channel comprises an 8-pole HTS
mini-filter with self-resonant rectangular spiral
resonators, and parallel lines input/output coupling

20   circuits. The input circuit of the multiplexer is in
the cascaded binary splitter form. Fig. 9a shows the
front view thereof, and Fig. 9b shows the cross section
view thereof.

Figure 10 shows a third embodiment of the present
25   invention of a microstrip line mini-multiplexer with
four channels. Each channel comprises an 8-pole HTS
mini-filter with self-resonant rectangular spiral
resonators, and parallel lines input/output coupling
circuits. The input circuit of the multiplexer is in

30   the multi-branch line form. Fig. 10a shows the front
view thereof, and Fig. 10b shows the cross section view
thereof.

Figure 11 shows an embodiment of the present
invention of a strip line 4-pole HTS mini-filter with
35   self-resonant rectangular spiral resonators with
rounded corners, center tuning pads, and parallel lines
input/output coupling circuits. Fig. 11a is a cross-
sectional view of the mini-filter, and Fig. 11b is a

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plan view as seen along lines and arrows A-A of Fig. 11a.

Fig. 12 shows the layout of a prototype 3-pole 0.16 GHz bandwidth centered at 5.94 GHz microstrip line HTS mini-filter with three self-resonant rectangular spiral resonators.

Fig. 13 shows the measured S-parameters data of the mini-filter shown in Fig. 12, in which Fig. 13a shows S_{11} versus frequency data, Fig. 13b shows S_{12} versus frequency data, Fig. 13c shows S_{21} versus frequency data, and Fig. 13d shows S_{22} versus frequency data.

Fig. 14 shows the measured S_{21} versus frequency data of the mini-filter shown in Fig. 12 to show the frequency shift caused by changing the medium of the space above the circuit.

Fig. 15 shows the measured third order intermodulation data of the mini-filter shown in Fig. 12 to show its nonlinearity behavior.

Detailed Description Of The Preferred Embodiments

The present invention provides for reducing the size of HTS filters without sacrificing performance and is based upon the use of self-resonant spiral resonators. The self-resonant spiral resonators have different shapes, including rectangular, rectangular with rounded corners, polygon and circular.

In order to reduce the size of the self-resonant spiral resonator and to confine its electromagnetic fields for minimizing the cross-talk, it is preferred to reduce the width of the gap between adjacent lines and reduce the center open area in the spiral resonator.

There are several methods to change the resonant frequency of the self-resonant spiral resonator: 1. Change the length of the spiral line; 2. Change the gap width between the adjacent lines of the spiral; 3. Place a conductive tuning pad at the center of the

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spiral. The third method can be used as fine frequency tuning.

The input and output coupling circuits of the mini-filter have two basic configurations: 1. Parallel lines configuration, which comprises a transmission line with one end connected to the mini-filter's connector via a gold pad on top of the line, the other end of the line is extended to be close by and in parallel with the spiral line of the first resonator (for the input circuit) or the last resonator (for the output circuit) to provide the input or output couplings for the filter; 2. Inserted line configuration, it comprises a transmission line with one end connected to the mini-filter's connector via a gold pad on top of the line, the other end of the line is extended to be inserted into the split spiral line of the first resonator (for the input circuit) or the last resonator (for the output circuit) to provide the input or output couplings for the filter.

The inter-resonator couplings between adjacent resonators in the mini-filter are provided by the overlapping of the electromagnetic fields at the edges of the adjacent resonators. The coupling strength can be adjusted by three ways: 1. Change the longitudinal distance between adjacent spiral resonators; 2. Change the orientation of the spiral resonators; 3. Shift the spiral resonator's location along the transverse direction. The third way can be used as coupling strength fine adjustment.

The mini-filters of this invention can be used to build mini-multiplexers, which have very small size without sacrificing performance. The mini-multiplexer comprises at least two channels with two mini-filters having slightly different non-overlapping frequency bands, an input distribution network, and an output port for each channel. The input distribution network has three different configurations: 1. Single binary splitter for the 2-channel mini-multiplexer, which uses

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a binary splitter to combine the two inputs of the two channels into a common port serving as the input for the mini-multiplexer; 2. Cascaded binary splitter, which consists of cascaded multiple stages of binary

5   splitters. In an N-stage cascaded distribution network, the 2^N output ports can be used for combining 2^N channels into a common port serving as the input for the mini-multiplexer; 3. Matched multi-branch lines, which consists of a common port as the input of the

10   mini-multiplexer and a multiple of branch lines connected to each channel. The length and width of these lines must appropriately chosen in such a way to achieve matching at the input and the output of the mini-multiplexer over the entire frequency band of the

15   mini-multiplexer.

The mini-filters and mini-multiplexers of this invention can be in the microstrip line form with one substrate and one ground plane, they also can be in the strip line form with a substrate, a superstrate and two

20   ground planes.

The conventional way to make small filters is using lumped circuit design, which utilizes lumped inductance and lumped capacitance to form resonators as the building blocks of the filter. A prior art spiral

25   inductor is shown in Fig. 1, in which Fig. 1a shows a rectangular shape and Fig. 1b shows a circular shape. Because the structural components of the inductor of Fig. 1a is the same as that of Fig. 1b (the only difference being the shape or configuration of the

30   spiral), the same reference numerals are used to denote the same structural components. Accordingly, numeral 1 designates the spiral conductor line and numeral 2 is the gap between adjacent turns of conductor line 1. Numerals 3 and 4 are the connecting pads located at the

35   terminal ends of conductor line 1 and numeral 5 is an open area without conductor at the center of the spiral inductor.

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The inductors shown in Fig. 1 are used in the conventional design for forming a lumped circuit resonator as the building blocks of a filter. In the prior art conventional design, the dimensions of the

5   lumped inductor must be carefully chosen such that to make its "self-resonant" frequency much higher than the highest frequency in the frequency band of the filter to avoid adverse interference from the self-resonance of the inductor. In order to do so, the gap 2 between

10   adjacent turns should be large compared to the width of conductor line 1, and the center open area 5 should be sufficiently large to let the magnetic fields generated by the current in the spiral line go through. Both measures cause magnetic fields that spread far beyond

15   the spiral inductor and cause cross-talk between adjacent circuits. As mentioned above, the other problem with the conventional design approach is the difficulty of connecting the terminal pad 4 located at the center of the spiral to other circuit components.

20   The present invention solves the problems by utilizing the self-resonance of these spiral inductors instead of avoiding it. The self-resonance occurs when the operating frequency equals to the self-resonance frequency, f_s:

25                        $$f_s = 1/\{2\pi[LC_p]^{1/2}\}$$

Here L is the inductance of the spiral, and C_p is the parasitic capacitance between adjacent turns. As mentioned above, for HTS filter design, it is desirable to reduce the size of the filter circuit which requires

30   that the open area of the spiral (numeral 5 in Fig. 1 a and 1b), as well as the gap (numeral 2 in Fig. 1a and 1b) between the conductor lines be minimized. These measures not only reduce the size of the spiral resonator, but also eliminate the need for additional

35   capacitance and the need for center connection. Moreover, these measures also confine most of the electromagnetic fields beneath the spiral resonator,

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hence solve the cross-talk problem caused by far reaching magnetic fields in the lumped conductor.

Fig. 2 shows four embodiments of the self-resonant spiral resonator as follows: rectangular is shown in Fig. 2a, a rectangular form with rounded corners is shown in Fig. 2b, a polygon shape is shown in Fig. 2c, and a circular shape shown in Fig. 2d. As seen in Figures 2a-2d, the self-resonant spiral resonators comprise a high temperature superconductor line oriented in a spiral fashion. The adjacent lines that form the spiral are spaced from each other by a gap distance which is less than the width of the line. The central opening in the resonator has a dimension approximately equal to that of the gap distance. It is understood, however, that the gap dimension has only one dimension (i.e., width) whereas the central opening has two dimensions (i.e., length (or height) and width). Accordingly, the phrase "dimension approximately equal to that of the gap distance" means that each dimension of the central opening is approximately the same as the single dimension of the gap distance. It should also be noted from Figures 2a-2d that the central opening is substantially symmetrical and has a shape correspondingly (although not necessarily identical to) the shape of the resonator.

With reference first to Fig. 2a, numeral 11 is the conductive line, numeral 12 is the gap between adjacent turns, numeral 13 is the center open area with its dimension close to the width of the reduced gap 12, and numeral 14 indicates the 90-degree sharp corners of the line 11.

The rf electrical charge and current are intended to concentrate at the line corners, which may reduce the power handling capability of the HTS rectangular spiral resonator. To solve the problem, Fig. 2b shows a second embodiment of the self-resonant spiral resonator in a rectangular form with rounded corners.

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In the embodiment of Fig. 2b, numeral 15 is the conductive line, numeral 16 is the gap between adjacent turns, numeral 17 is the reduced center open area with its dimension close to the width of the reduced gap 16,

5   and numeral 18 indicates the rounded corners of the line 15.

Fig. 2c shows a third embodiment of the self-resonant spiral resonator in a octagon form in which numeral 20 is the conductive line, numeral 21 is the

10   gap between adjacent turns, numeral 22 is the reduced center open area with its dimension close to the width of the reduced gap 21 and numeral 23 indicates the 120-degree corners of the line 20. The self-resonant spiral resonator is not restricted to this particular

15   octagon form. Rather, it can be of any polygon shape, provided that it has more than four corners to distinguish the rectangular shapes.

Fig. 2d shows a fourth embodiment of the self-resonant spiral resonator in a circular form. In this

20   embodiment, numeral 25 is the conductive line, numeral 26 is the gap between adjacent turns, numeral 27 is the reduced center open area with its dimension close to the width of the reduced gap 26 and numeral 28 is a conductive tuning pad located at the center open area

25   27 for fine tuning the resonant frequency of the spiral resonator. The tuning pad is not restricted to this specific form of circular shape, but instead may be in rectangular form or any arbitrary forms. It is further to be understood that the tuning pad may be used with

30   any of the other configurations described above and is not restricted in its use to the spiral resonator having the circular configuration.

Fig. 3 shows a first embodiment of the 4-pole HTS mini-filter circuit having four self-resonant spiral

35   resonators (in this case having a rectangular configuration with rounded corners) as its frequency selecting element. Fig. 3a shows the top or front view of the filter, and Fig. 3b shows a cross section view.

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In Figures 3a and 3b, numeral 30 is a dielectric
substrate with a front side and a back side. The HTS
filter mini-circuit is disposed on the front side of
the substrate 30 as shown in Fig. 3a and 3b. The back

5   side of the substrate 30 (which is seen in the cross
sectional view of Fig. 3b but is not seen in the view
of Fig. 3a) is disposed with a blank HTS film 31 (see
Fig. 3b) serving as the ground of the mini-filter
circuit. A gold film 32 (see Fig. 3b) is disposed on

10   top of HTS film 31 and functions as the contact to the
mini-filter's case, which is not shown. In Fig. 3a,
numerals 33, 34, 33a, and 34a are four self-resonant
rectangular spiral resonators with rounded corners.
The inter-resonator couplings are provided by the

15   coupling gaps, 38, 38a, and 38b, between the adjacent
resonators. The input coupling circuit is in a
parallel lines form, which comprises an input line 35
and the coupling gap 39 between 35 and the first
resonator 33. The output coupling circuit is in a

20   parallel lines form, which comprises an output line 35a
and the coupling gap 39a between 35a and the last
resonator 33a. Two tuning pads 36, 36a are placed at
the center of resonators 34 and 34a, respectively, for
fine tuning the resonant frequency of the resonators 34

25   and 34a. Gold connecting pads 37 and 37a are disposed
on the input and output line 35 and 35a, respectively,
providing the connections to the mini-filter's
connectors, not shown.

Fig. 4 shows a second embodiment of the 4-pole HTS

30   mini-filter circuit having four self-resonant
rectangular spiral resonators as its frequency
selecting element, in which Fig. 4a shows the front
view and Fig. 4b shows the cross section view. Numeral
40 is a dielectric substrate with a front side and a

35   back side. The HTS mini-filter circuit is disposed on
the front side of the substrate 40 as shown in Fig. 3a.
As indicated by the cross section view shown in
Fig. 3b, the back side of the substrate 40 is disposed

with a blank HTS film 41 serving as the ground of the mini-filter circuit, and a gold film 42 is disposed on top of 41 serving as the contact to the mini-filter's case, which is not shown. In Fig. 4a, numerals 43, 44,

5 43a, and 44a are the four self-resonant rectangular spiral resonators. The inter-resonator couplings are provided by the coupling gaps 49, 49a, 49b between adjacent resonators. In this particular case, the inter-resonator coupling strength is adjusted by

10 changing the gap width between the adjacent resonators, as well as by shifting the resonator's location in the transverse direction for the fine adjustment. The input coupling circuit is in the inserted line form, which comprises an input line 45 with its extended

15 narrower line 46 inserted into the split spiral line of the first resonator 43 with a coupling gap 47 between them. The output coupling circuit is in the inserted line form, which comprises an output line 45a with its extended narrower line 46a inserted into the split

20 spiral line of the last resonator 43a with a coupling gap 47a between them. Gold connecting pads 48 and 48a are disposed on the input and output lines 45 and 45a, respectively, providing the connections to the mini-filter's connectors, not shown.

25 Fig. 5 shows a third embodiment of the 4-pole HTS mini-filter circuit having self-resonant four octagon spiral resonators as its frequency selecting element, in which Fig. 5a shows the front view, and Fig. 5b shows the cross section view. Numeral 50 is a

30 dielectric substrate with a front side and a back side. The HTS mini-filter circuit is disposed on the front side of the substrate 50 as shown in Fig. 5a. As indicated by the cross section view shown in Fig. 5b, the back side of the substrate 50 is disposed with a

35 blank HTS film 51 serving as the ground of the mini-filter circuit, and a gold film 52 is disposed on top of blank HTS film 51 serving as the contact to the mini-filter's case, not shown. In Fig. 5a, numerals

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53, 54, 53a, and 54a are the four self-resonant octagon spiral resonators. The inter-resonator couplings are provided by the coupling gaps 59, 59a, 59b, between adjacent resonators. In this particular case, the

5 inter-resonator coupling strength is adjusted by changing the gap width between the adjacent resonators, as well as by shifting the resonator's location in the transverse direction for the fine adjustment. The input coupling circuit is in the inserted line form,

10 which comprises an input line 55 with its extended line 56 inserted into the split spiral line of the first resonator 53 with a coupling gap 57 between them. The output coupling circuit is in the inserted line form, which comprises an output line 55a with its extended

15 line 56a inserted into the split spiral line of the last resonator 53a with a coupling gap 57a between them. Gold connecting pads 58 and 58a are disposed on the input and output lines 55 and 55a, respectively, providing the connections to the mini-filter's

20 connectors, not shown.

Fig. 6 shows a fourth embodiment of the 4-pole HTS mini-filter circuit having four self-resonant circular spiral resonators as its frequency selecting element, in which Fig. 6a shows the circuit front view, and

25 Fig. 6b shows the cross section view. Numeral 60 is a dielectric substrate with a front side and a back side. The HTS mini-filter circuit is disposed on the front side of the substrate 60 as shown in Fig. 6a. As indicated by the cross section view shown in Fig. 6b,

30 the back side of the substrate 60 is disposed with a blank HTS film 61 serving as the ground of the mini-filter circuit, and a gold film 62 is disposed on top of blank HTS film 61 serving as the contact to the mini-filter's case, not shown. In Fig. 6a, numerals

35 · 63, 64, 63a, and 64a are the four self-resonant circular spiral resonators. The inter-resonator couplings are provided by the coupling gaps 63b, 63c, 63d, between adjacent resonators. The input coupling

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circuit is in the parallel line form, which comprises an input line 66 and an extended line 67, the input coupling is provided by the gap 69 between 67 and the first resonator 63. The output coupling circuit is in

5   the parallel line form, which comprises an output line 66a and an extended line 67a, the output coupling is provided by the gap 69a between 67 and the first resonator 63. Two tuning pads 65, 65a are placed at the center of resonators 63 and 63a, respectively, for

10 fine tuning the resonant frequency of the resonators 63 and 63a. Gold connecting pads 68 and 68a are disposed on the input and output lines 66 and 66a, respectively, providing the connections to the mini-filter's connectors, not shown in the figures.

15   Fig. 7 shows one embodiment of a 5-pole HTS mini-filter circuit having five self-resonant rectangular spiral resonators as its frequency selecting element, in which Fig. 7a shows the circuit front view, and Fig. 7b shows the cross section view. Numeral 70 is a

20 dielectric substrate with a front side and a back side. The HTS mini-filter circuit is disposed on the front side of the substrate 70 as shown in Fig. 7a. As indicated by the cross section view shown in Fig.' 7b, the back side of the substrate 70 is disposed with a

25 blank HTS film 71 serving as the ground of the mini-filter circuit, and a gold film 72 is disposed on top of blank HTS film 71 serving as the contact to the mini-filter's case, which is not shown. In Fig. 7a, numerals 73, 74, 73a, and 74a are the four self-

30 resonant rectangular single spiral resonators, 75 is a self-resonant rectangular double spiral resonator, which is centrally located and thus serves as the middle resonator. The use of double spiral resonator 75 at the middle of the 5-pole filter is to make the

35 circuit geometry symmetrical with respect to the input and the output. This approach is also suitable for any symmetrical mini-filter with odd number poles. The inter-resonator couplings are provided by the coupling

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gaps 75a, 75b, 75c, 75d, between adjacent resonators.
In this particular case, the inter-resonator coupling
strength is adjusted by changing the gap width between
the adjacent resonators. The input coupling circuit is

5 in an inserted line form, which comprises an input line
76 with its extended narrower line 77 inserted into the
split spiral line of first resonator 73 with a coupling
gap 78 between them. The output coupling circuit is in
a inserted line form, which comprises an output line

10 76a with its extended narrower line 77a inserted into
the split spiral line of last resonator 73a with a
coupling gap 78a between them. Gold connecting pads 79
and 79a are disposed on the input and output lines 76
and 76a, respectively, providing the connections to the

15 mini-filter's connectors, not shown.

Fig. 8 shows a 2-channel mini-multiplexer, each
channel has a 8-pole HTS mini-filter 83, 83a,
respectively, with eight rectangular self-resonant
spiral resonators. Fig. 8a shows the front view and

20 Fig. 8b shows the cross section view. Numeral 80 is a
dielectric substrate with a front side and a back side.
The HTS mini-multiplexer circuit is disposed on the
front side of substrate 80 as shown in Fig. 8a. As
indicated by the cross section view shown in Fig. 8b,

25 the back side of the substrate 80 is disposed with a
blank HTS film 81 serving as the ground of the mini-
multiplexer circuit, and a gold film 82 is disposed on
top of blank HTS film 81 serving as the contact to the
mini-multiplexer's case, which is not shown. The

30 frequency bands of mini-filters 83 and 83a are slightly
different and without overlapping to form two channels.
The input coupling circuits of mini-filters 83 and 83a
are in the parallel lines form, which comprise input
lines 84 and 84a and the gaps 84b, 84c, respectively,

35 between input lines 84 and 84a and the first spiral
resonator of filters 83 and 83a, respectively. A
distribution network in a single binary splitter form
serves as the input of the multiplexer, which comprises

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the common input line 86, a T-junction 87, and branch
lines 85 and 85a, with one end of each of the branch
lines 85 and 85a commonly connected to T-junction 87,
and the other end thereof connected to coupling lines
5   84 and 84a, respectively. The dimensions of coupling
lines 84 and 84a, branch lines 85 and 85a, common input
line 86 and T-junction 87 are selected in such a way to
provide the input impedance matching of the mini-
multiplexer over the frequency range covering the two
10   frequency bands of filters 83 and 83a. The output
coupling circuits of filters 83 and 83a are in the
parallel lines form, which comprise the output lines
87a and 87b, and the gap 87c, 87d, respectively,
between them and the last resonator of filters 83 or
15   83a. Output lines 87a and 87b also serve as the output
lines for the two channels of the mini-multiplexer.
Gold connecting pads 88, 88a and 88b are disposed on
the input line 86, and output lines 87a and 87b,
respectively, providing the connections to the mini-
20   multiplexer's connectors, not shown.

It should be understood that the form of the self-
resonant spiral resonators in the mini-multiplexer is
not restricted to the rectangular form illustrated in
Fig. 8, but rather they can be of any configuration
25   such as shown in Figs. 2a-2d or combinations thereof.
Further it is to be understood that the form of the
input and output coupling circuits of the mini-filters
in the mini-multiplexer is not restricted to the
parallel line form shown in Fig. 8, but instead other
30   line forms may be used, such as the inserted line form
or combinations of inserted line form and parallel line
form.

Fig. 9 shows a second embodiment of the 4-channel
mini-multiplexer, each channel having an 8-pole HTS
35   mini-filter with eight self-resonant rectangular spiral
resonators, in which Fig. 9a shown the front view and
Fig. 9b shows the cross section view. Numeral 90 is a
dielectric substrate with a front side and a back side.

20

The HTS mini-multiplexer circuit is disposed on the front side of substrate 90 as shown in Fig. 9a. As indicated by the cross section view shown in Fig. 9b, the back side of the substrate 90 is disposed with a

5   blank HTS film 91 serving as the ground of the mini-multiplexer circuit, and a gold film 92 is disposed on top of blank HTS film 91 serving as the contact to the mini-multiplexers case, not shown. Numerals 93 and 93a are used to designate two 2-channel mini-multiplexer

10   similar to that shown in Fig. 8. The frequency bands of mini-multiplexers 93 and 93a are slightly different and without overlapping. The distribution network at the input of the 4-channel mini-multiplexer is in a 2-stage cascaded binary splitter form. The first stage

15   comprises a common input line 95, a T-junction 96 and two branch lines 94 and 94a, with one end of each of the branch lines 94 and 94a commonly connected to T-junction 96, and the other end thereof connected to the input lines 94b and 94c, respectively, of the second

20   stage. The second stage comprises two binary splitters, which actually are the input binary splitters of the two 2-channel mini-multiplexers 93 and 93a, and comprise input lines 94b and 94c; T-junctions 94d and 94e; branch lines 94f, 94g, 94h and 94i; and

25   input lines 94j, 94k, 94l and 94m, as shown in Fig. 9a. The dimensions of mini-multiplexers 93 and 93a, branch lines 94 and 94a, input lines 94b and 94c, T-junctions 94d and 94e, branch lines 94f, 94g, 94h and 94i, input lines 94j, 94k, 94l and 94m, common input line 95 and

30   T-junction 96 are selected in such a way to provide the input impedance matching of the mini-multiplexer over the frequency range covering the four frequency bands of the 4-channel mini-multiplexer. The output circuits of the 4-channel mini-multiplexer comprise the two 2-

35   channel mini-multiplexers' output lines: 97, 97a, 97b, 97c, which serve as the four output lines for the 4-channel mini-multiplexer as shown in Fig. 9a.

Fig. 10 shows a third embodiment of the 4-channel
mini-multiplexer, each channel comprising an 8-pole HTS
mini-filter 103, 103a, 103b, 103c (see Fig. 10a), with
eight self-resonant rectangular spiral resonators.

5   Fig. 10a shows the front view and Fig. 10b shows the
cross section view. Numeral 100 is a dielectric
substrate with a front side and a back side. The HTS
mini-multiplexer circuit is disposed on the front side
of substrate 100 as shown in Fig. 10a. As indicated by

10   the cross section view shown in Fig. 10b, the back side
of the substrate 100 is disposed with a blank HTS film
101 serving as the ground of the mini-multiplexer
circuit, and a gold film 102 is disposed on top of
blank HTS film 101 serving as the contact to the mini-

15   multiplexer's case, which is not shown. The frequency
bands of filters 103, 103a, 103b, and 103c are slightly
different and without overlapping to form four
channels. The distribution network at the input of the
4-channel mini-multiplexer is in a matched branch lines

20   form, which comprises a common input line 106, a
matching section 105, line sections 104, 104a, 104b,
104c, and five junctions: 107, 107a, 107b, 107c and
107d. The dimensions of line sections 104, 104a, 104b
and 104c, matching section 105, common input line 106,

25   and junctions 107, 107a, 107b, 107c and 107d, are
selected in such a way to provide the input impedance
matching of the mini-multiplexer over the frequency
range covering the four frequency bands of the 4-
channel mini-multiplexer. The output circuits of the

30   4-channel mini-multiplexer comprise the four mini-
filter's output lines: 108, 108a, 108b, 108c, which
serve as the four output lines for the 4-channel mini-
multiplexer as shown in Fig. 10a.

       Fig. 11 shows an example of a 4-pole HTS filter in
35   the strip line form with four rectangular self-resonant
spiral resonators with rounded corners as its frequency
selecting element. Fig. 11a is a cross sectional view
of the filter and Fig. 11b is a view as seen along

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lines and arrows A-A of Fig. 11a. Numeral 110 is a
dielectric substrate with a front side and a back side.
The HTS filter circuit 113 is disposed on the front
side of substrate 110 as seen in Fig. 11b. As shown in

5 Fig. 11a, a first blank HTS film 111 is disposed on the
back side of substrate 110 serving as one of the two
ground planes for the strip line, a first gold film 112
is disposed on top of first blank HTS film 111 serving
as the contact to the filter's case, which is not shown

10 in the figures. Numeral 110a is a dielectric
superstrate with a front side and a back side. As
shown in Fig. 11a, a second blank HTS film 111a is
disposed on the back side of superstrate 110a serving
as one of the two ground planes for the strip line, a

15 second gold film 112a is disposed on top of second
blank HTS film 111a serving as the contact to the
filter's case (not shown). As is also shown in
Fig. 11a, superstrate 110a is smaller in size than
substrate 110 whereby the first end (e.g., microstrip

20 line 115 and gold contact pad 116) of the input
coupling circuit and the first end (e.g., microstrip
line 115a and gold contact pad 116a) of the output
coupling circuit are each located outside the
dimensions of superstrate 110a, that is, they are not

25 covered by superstrate 110a. Although not shown, it is
understood that the mirror image of HTS filter circuit
113 could also be disposed on the front side of
superstrate 110a and the two mirror image circuits
aligned. As shown in Fig. 11b, the input and output

30 strip lines 114 and 114a are extended into broader
microstrip lines 115 and 115a, respectively, on the
substrate 110. Gold contact pads 116 and 116a are
disposed on microstrip lines 115 and 115a, respectively
(also seen in Fig. 11a), providing the connections to

35 the filter case (not shown). The line width of output
strip lines 114 and 114a, and microstrip lines 115 and
115a, are selected in such a way to achieve the
impedance matching at the input and the output.

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In all of the embodiments described above, it is preferred that the high temperature superconductor is selected from the group consisting of $YBa_2Cu_3O_7$, $Tl_2Ba_2CaCu_2O_8$, $TlBa_2Ca_2Cu_3O_9$, $(TlPb)Sr_2CaCu_2O_7$ and

5    $(TlPb)Sr_2Ca_2Cu_3O_9$. It is also preferred that the substrate and superstrate are independently selected from the group consisting of $LaAlO_3$, MgO, $LiNbO_3$, sapphire and quartz.

EXAMPLE

10   A mini-filter having the circuit layout shown in Figure 12 was prepared. It is a 3-pole 0.16 GHz bandwidth centered at 5.94 GHz mini filter in the microstrip line form. It consists of three rectangular self-resonant spiral resonators, 121, 121a, 121b, each

15   having a tuning pad at the center, 122, 122a, 122b, parallel lines input and output coupling circuits, 123, 123a. The substrate 120 is made of $LaAlO_3$ with dimensions of 5.250 mm x 3.000 mm x 0.508 mm. The HTS thin film is $Tl_2Ba_2CaCu_2O_8$. The filter was fabricated,

20   and tested at 77 K. The measured S-parameter data are shown in Fig. 13, in which Fig. 13a shows S_{11} versus frequency data, Fig. 13b shows S_{12} versus frequency data, Fig. 13c shows S_{21} versus frequency data, Fig. 13d shows S_{22} versus frequency data. S_{11} is the

25   magnitude of the reflection coefficient from the input port; S_{21} is the magnitude of the transmitting coefficient from the input port to the output port; S_{22} is the magnitude of the reflection coefficient from the output port; and S_{12} is the magnitude of the

30   transmitting coefficient from the output port to the input port. The measured data were in agreement with the computer simulated data very well, the center frequency difference was less than 0.1%.

The mini-filter was also tested under two

35   different conditions. That is, it was tested in the air with a relative dielectric constant of approximately 1.00, and also was tested in liquid nitrogen with a relative dielectric constant of

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approximately 1.46. Fig. 14 shows the S_{21} versus frequency data, in which 131 is for the air data and 132 is for the liquid nitrogen data. The results indicate a frequency shift of only 0.04 GHz

5 corresponding to 0.67% of the center frequency. The very small frequency shift is an indirect indication of most electromagnetic fields confinement beneath the spiral resonators.

The filter was also tested under power from 0.01

10 watt up to 0.2 watt cw rf power without measurable changes in its S_{21}. The Third Order Intercept (TOI) test data are shown in Fig. 15 in a log-log scale, in which 141 is the best fit straight line with a slope of 1 for the sum of two fundamental frequencies, 142 is

15 the best fit straight line with a slope of 3 for the third order intermadulation. The intercept of these two lines gives a TOI of 39.5 dBm. Both the power and the TOI test data are in line with similar conventional HTS filters with the same line width and ten times

20 larger size. These test results confirmed that the one order of magnitude reduction of size does not degrade the mini-filter's performance compared to the conventional design.